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ASSESSMENT OF TIDAL WETLAND HABITAT

AND UCTIVITY

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The state, regional and federal authorities charged with management of wetland resources all have a basic requirement for information on the boundaries and areal extent of the marshes under their jurisdiction, and the acquisition of this information using remote sensing has provided a significant reduction in inventory costs over more traditional survey techniques. During the course of these projects it was found that major emergent plant communities within the areas designated as wetlands could often be discriminated using the same photographic data collected for delineation of the wetland/upland boundary. Information on distribution of major plant species, drainage patterns, etc. is of value to management authorities when conflicting interests require decisions regarding relative wetland values, and allocation of the resource to various competing uses.

The spectral contrast between canopies composed of different marsh plants is produced by a combination of the optical properties of individual vegetative components (leaves, stems, etc.) and the effects of plant growth form, density and height, tidal stage, soil type, etc. which determine the reflectance of the composite soil/canopy surface when viewed by a remote sensor. Working in Georgia, Reimold et al. (1972) and Pfeiffer et al. (1973), measured the reflectance of individual leaves of S. alterniflora and Juncus roemerianus and found significant interspecific differences, particularly in the infrared (0.7 µm - 1.4 µm), where Juncus leaves exhibited much higher reflectance. Recent data collected in Delaware, where the major species present are S. alterniflora, Spartina patens and Distichlis spicata, suggest the importance of canopy structure (Bartlett, 1979). Leaf reflectances are comparable for all three species yet stands of S. alterniflora are spectrally distinct from the other two.

In temperate regions there may be extensive seasonal effects on reflectance signatures as both canopy structure and leaf optical characteristics change. Carter and Schubert (1974) measured canopy reflectance over several marsh cover types (Spartina alterniflora, Spartina patens, Iva frutescens and organic mud flat) in Virginia between May and October. Analysis indicated that all four classes were spectrally discriminable

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in October although contrast between individual classes was sometimes greatest during other months. In Delaware, spectroradiometer measurements were made throughout the year and optimal spectral discrimination between the major communities - S. alterniflora vs. S. patens and D. Spicata - occured in December when more rapid senescence of S. patens and D. spicata in response to approaching winter caused reflectance signatures to diverge.

Reimold, et al. (1972) found that tonal variations of S. alterniflora recorded on aerial color infrared film could be associated with variations in emergent biomass. This relationship has been quantified in Delaware where it was found that the infrared/red reflectance ratio measured in situ was linearly correlated with emergent green biomass (r^2 = .78) for S. alterniflora (Bartlett, 1979).

Assessment of wetland habitats by remote sensing is not without problems. Landsat data, in particular, is subject to resolution limitations which make its application in statutory wetland inventories of minor value (Penney and Gordon, 1975). In addition, spectral similarities between wetlands and uplands can limit categorization accuracy (Bartlett, et al., 1977, Klemas, et al., 1975). Examination of the physical basis of wetlands reflectance using in situ radiometry and application of data collected by scanners such as the Landsat/MSS have the potential for providing knowledge of the condition of the habitat (biomass, etc.) and to aid in exploiting seasonal divergence of reflectance signatures to improve species discrimination.

1. INTRODUCTION

The tidal wetland is an environment which is unique, both in its contributions to the functioning of larger ecosystems and in the often destructive pressures exerted upon it by man. Tidal wetlands have been recently recognized as providing a vital link in the chain of marine energy flow through their extremely efficient transfer of solar energy into forms which are usable by a wide variety of estuarine organisms (Odum, 1961). A major portion of this transfer is performed by halophytic (salt tolerant) plants which are remarkable both for their enormous productivity -- comparable to the most intensely cultivated agricultural lands (Odum, 1971), and their wide distribution throughout the world's coastal areas (Chapman, 1960).

At the same time, marshes have traditionally been perceived as waste land, contributing to the quality of human life only when the natural system is replaced by more nearly terrestrial or marine environments suitable for human habitation or navigation. As a consequence, tidal wetlands are subjected to extreme pressure through their coexistence in coastal areas with the majority of the world's human population. The result in many areas, such as the East Coast of the United States, has been the rapid destruction of a significant percentage of natural tidal wetlands, possibly to the detriment of the marine environment and its living resources (Teal and Teal, 1969). Recognition of wetland values and of the need to assess the impact of wetland destruction has produced legislation at the federal level and in many states the goal of which is to provide effective management of this fragile resource. A requirement of all such management programs is information on the boundaries, extent and condition of wetland areas -- information which is difficult to acquire in the expansive, often hostile wetland environment.

Efforts to accumulate data concerning tidal wetlands have recently come to rely more and more on remote sensing techniques. These techniques have been extensively developed for the characterization of emergent vegetation - so important a part of the wetlands ecosystem - and are now routinely used to identify wetland boundaries because of the large reduction in time and effort achieved over that required by conventional surveys. The wetland inventory programs of coastal states rely primarily on aerial photography for production of maps or other products. The U.S. Fish and Wildlife Service is conducting a National Wetlands Inventory using aerial photography as the basic data source. Aerial photographic inventories provide synoptic information the scale of which can be adjusted to provide the spatial accuracy required by many statutory management programs. For a comprehensive, up-to-date summary of inventory programs, techniques and problems the reader is referred to the excellent paper by Carter (1978).

Once the tidal wetland resource has been inventoried, the management authority must make decisions concerning the allocation of that resource to the various functions competing for its use. This process, too, requires data but the impact of remote sensing on collection of such information has thus far been limited. The reasons for this are many but

most stem from a substantial lack of quantitative knowledge of the interactions of electro-magnetic radiation with wetland cover-types and a resultant inability to measure the physical/ecological criteria used in management decisions. Location and measurement of wetland boundaries and extent using remote sensing is a relatively modest task when compared with the gathering of data concerning the function or condition of the ecosystem. Nevertheless, if remote sensing can be applied in these areas, one can anticipate that the same advantages of economical, synoptic data now recognized for wetland inventories will be obtained in wetland habitat assessment. The intention of this paper is to review the past research in and potential of remote sensing for quantitative wetland habitat assessment.

2. REMOTE SENSING OF SPECIES COMPOSITION

One area in which remote sensing is currently contributing to evaluation of wetland environments is through mapping of emergent plant species composition. Because the dominant halophytic plants are quite sensitive to the extent and duration of tidal inundation, the distribution of plant species can be used as an indicator of tidal and salinity regimes within the marsh (Anderson *et al.*, 1973). In addition, the combination of tidal and vegetative factors exert great control over the characteristics of the habitat available for other life forms. Among the management criteria applied to wetlands are their function in absorbing flood waters, in cycling of water-borne nutrients and detritus, and in providing habitat for a variety of marine, estuarine and terrestrial organisms. Knowledge of plant species composition allows some conclusions to be drawn concerning the potential for flood mitigation, tidal interchange with adjacent estuarine waters and the availability of food and shelter for many invertebrates, fish, mammals and waterfowl. Such conclusions are admittedly indirect and subject to local variability and interpreters' biases. Nevertheless, the collection of such information using conventional *in situ* procedures can be prohibitively expensive in large wetland areas.

The interpretation of wetland plant species composition relies on essentially the same type of criteria used for delineation of wetlands; namely; the discrimination of one species from another. Spectral signatures by which particular species may be identified are mutually determined by the spectro-optical characteristics of the materials comprising a particular cover-type (leaves, stems, soil, etc.) and on the way in which these components are arranged - i.e., the canopy structure. If medium or large scale imagery is manually interpreted, canopy effects on image texture can also be used for identification. The potential for discriminating one species from another in remotely sensed data thus depends upon the degree to which the above factors combine to produce unique, distinguishable image characteristics for those species. Working in Georgia, Reimold *et al.* (1972) found that the spectral contrast observed in color infrared photography between the major species - *Spartina alterniflora* and *Juncus roemerianus* - was apparently based on large differences in the reflectance of individual leaves of the two species, particularly in the near infrared (0.7 μm - 1.3 μm) where reflectance of *J. roemerianus* leaves was higher than that of *S. alterniflora* leaves. Working in the same area, Pfeiffer *et al.* (1973) measured "community" (canopy) reflectance of these species and found that variability in the

canopy height of S. alterniflora produced variations in canopy reflectance for this species, especially in the near infrared region where leaf reflectance contrast with J. roemerianus was high. The magnitude of the variation due to canopy structure was sufficient to mask the spectral contrast with J. roemerianus in some cases. Further indication of the importance of canopy effects has been found in Delaware (Bartlett, 1979) where measurements of canopy and leaf reflectance were made for the dominant species - S. alterniflora, S. patens and Distichlis spicata. Leaf reflectances for all three species were found to be quite similar yet S. alterniflora canopy reflectance is, for most of the year, significantly lower at all wavelengths than that of the other two species. The short, dense canopies of S. patens and D. spicata, often composed of nearly horizontal stems and leaves, provide a continuous, uniform reflecting surface which results in high canopy reflectance. S. alterniflora, on the other hand, is characterized by a less dense canopy of vertically oriented stems producing shading within the canopy which reduces the reflectance observed. As in Georgia, however, it was found that variability in canopy structure within species could produce convergence of the normally distinct spectral signatures (Bartlett et al., 1977; Klemas et al, 1975).

In temperate regions there may be extensive seasonal effects on vegetative reflectance signatures as both canopy structure and leaf optical characteristics change. Carter and Schubert (1974) measured canopy reflectance over several marsh cover types (Spartina alterniflora, Spartina patens, Iva frutescens and organic mud flat) in Virginia between May and October. Analysis indicated that all four classes were spectrally discriminable in October although contrast between individual classes was sometimes greatest during other months. In Delaware, spectroradiometer measurements were made of S. alterniflora, S. patens and D. spicata throughout the year in order to investigate seasonal effects on canopy reflectance and two salient relationships emerged. First, in the spring (April through June) the new growth of highly absorptive green vegetation of S. patens and D. spicata began obscuring the low, matted residual canopy and thus reducing visible reflectance much more quickly than did the new growth of S. alterniflora. New S. alterniflora shoots were emerging at the base of the still upright, relatively tall canopy and thus did not reduce visible reflectance extensively through absorption. The result was convergence of the spectral signatures for the two plant types, particularly in the visible wavelengths (0.5 μm - 0.7 μm). The effect was not noticeable in Virginia (Carter and Schubert, 1974); probably because winter scouring by tides removed most residual S. alterniflora from the study site, enhancing spectral contrast with other species during the spring. Second, in late fall (November-December), the leaves of S. patens and D. spicata reached senescence in response to cold temperatures more rapidly than did the leaves of S. alterniflora. Thus, visible canopy reflectance of S. patens and D. spicata increased relative to that of S. alterniflora and enhanced contrast was observed. The dual effects of canopy structure (in the spring) and of leaf optical characteristics (in the fall) are thus illustrated with obvious implications for planning of remote sensing missions. It is also clear that seasonal trends in spectral contrast between species are highly dependant on local climatic and tidal conditions.

In summary, while major wetland species are spectrally distinct enough for interpretation of species composition, ambiguities exist which under some circumstances can be minimized through quantitative research directed at the proper choice of seasonal imagery. In some cases, such as in Delaware and New Jersey, traditional reliance on imagery acquired near the peak of the growing season may not be justified.

3. REMOTE SENSING OF EMERGENT BIOMASS

A major criterion often applied to evaluation of tidal wetlands is emergent primary production (amount of emergent plant material produced per unit time). Conventional field studies usually employ periodic harvesting of measured quadrats of vegetation and subsequent sorting, drying and weighing of the samples for production determination. Harvesting is a laborious, time consuming task which is not often feasible if information over large areas is desired. The result is a lack of data in such areas where if remote sensing could be applied, a valuable contribution could be made.

Carter (1976) used area measurements of plant species based on interpretation of Landsat data along with typical values for primary production of each species to estimate primary production for a marsh island in Virginia. Such estimates are limited, however, in that large intraspecific variations in production, even within a small area, are known to occur. There are indications that biomass (amount of organic material per unit area) for selected wetlands species can be estimated directly from remotely sensed data and applied to calculations of primary production. The response of wetland canopy reflectance to characteristics such as plant density and canopy height described above should facilitate estimation of biomass. In addition, spectral techniques have already been used to estimate biomass of rangeland grasses (Seevers et al., 1975; Pearson and Miller, 1972) and of agricultural crops (Tucker, 1979).

Reimold, et al., (1972) found that tonal variations of S. alterniflora recorded on aerial color infrared film could be associated with variations in emergent biomass. Increases in the relative intensity of infrared reflectance of stands having larger amounts of biomass produced "redder" image tones. The relationship observed was a somewhat qualitative one but illustrated the potential for more accurate work based on more easily quantifiable radiometric data. Using in situ spectoradiometer measurements it was found that green biomass of S. alterniflora in Delaware was strongly correlated with the infrared (0.8 μm - 1.1 μm)/red (0.6 μm - 0.7 μm) reflectance ratio (Bartlett, 1979). The basis for the correlation appears to be that red canopy reflectance is inversely related to the proportion of green vegetation in the canopy while infrared canopy reflectance is directly related to the total biomass of vegetation present. Thus, the reflectance ratio is highly correlated ($r^2 = .78$) with green biomass (g dry wt./m^2). The relationship is linear over the entire range of green biomass measured (20-1000 g dry wt./m^2) and thus appears to offer great potential for remote estimation of biomass for this species.

Drake (1976) made *in situ* spectral measurements of *S. patens*, *D. spicata* and *Scirpus olneyi* and found high correlations of red (0.66 μm - 0.71 μm) reflectance with green biomass (r^2 = 0.74 - 0.83). The range of biomass tested was restricted, however (0-350 g dry wt./m^2). It seems likely that Drake's results were produced by high intercorrelation between the percentage and the mass of green vegetation. Similar results, using visible reflectance alone, have been reported in Western rangelands (Seevers *et al.*, 1975).

4, PROBLEMS ASSOCIATED WITH EVALUATION OF WETLAND BIOMASS USING REMOTE SENSING

There are several difficulties encountered when one seeks to extend the use of remote sensing analysis beyond species delineation into the areas of wetland function or condition.

While aerial photography has been used effectively for mapping species distribution in many wetland areas, interpretation of biomass is restricted by non-significant variations in image tone and the extent of the interpreter's knowledge of the specific area in question. Extension of such signatures to other areas or data sets, even within the same general region, is difficult without more field studies. Similarly, estimates of primary production based on species composition and mean production values for each species are subject to local variability, making signature extension heavily dependant on available ground truth.

Alternatively, more generally applicable analysis may be possible using data provided by field radiometers or scanners mounted on aerial or orbital platforms. While ground truth is still required, extension of signatures within a particular region is made easier as the analysis relies on direct response to biomass rather than on assumptions concerning local conditions. Nevertheless, use of radiometric data presents a new suite of potential difficulties. Field spectral studies do not possess the major advantages of remote sensing with regard to cost-effective data collection over large areas (although there are indications that they may be preferable to harvest techniques under some circumstances). The most readily available source of remote scanner data is the Landsat/MSS. Landsat data, however, is subject to resolution limitations (both spectral and spatial) which can restrict species categorization, identification of boundary picture elements and mensuration accuracies (Bartlett *et al.*, 1977; Carter, 1978). Further, as quantitative surface reflectance data is required, Landsat measurements must be corrected for effects of sun angle and atmospheric attenuation of the upwelling signal. Techniques for atmospheric correction of Landsat data have been successfully applied but are not without some inaccuracies (Bartlett *et al.*, 1977; Rogers *et al.*, 1973).

As the relationships used to estimate biomass are species-specific, accurate identification of species is necessary before analysis for biomass. As discussed above, some of the difficulties in this regard may be mitigated by choice of data acquired during optimal seasons for species discrimination (Bartlett *et al.*, 1977, Carter and Schubert, 1974).

Finally, many state and local authorities may be ill-equipped for the quantitative analysis of atmospheric conditions and target reflectance required. In order for widespread realization of the potential for remote sensing analysis of wetland condition to occur, the technology required must pass from the research communitiy into the hands of the private remote sensing service community and/or management authorities.

5. THE FUTURE OF REMOTE SENSING IN ASSESSMENT OF WETLAND HABITAT AND PRODUCTIVITY

The utility of aerial photographic interpretation for delineation of wetland boundaries and mapping of species composition appears to be well established as evidenced by its use in many state and federal operational inventories (Carter, 1978). Valuable information for evaluation of the wetland habitat can be inferred from species composition and distribution as interpreted from photographs or, for large scale studies, from Landsat/MSS data (Anderson *et al.*, 1973; Carter, 1978; Klemas *et al.*, 1975).

There are indications of future potential for quantitative remote sensing analysis of biomass/productivity for important wetland species (Bartlett, 1979; Drake, 1976; Reimold *et al.*, 1972); however, continued evaluation and development of this potential is needed in several areas:

1) The spectral and spatial resolution of Landsat/MSS data is such that its utility is restricted to assessment of relatively large areas of wetland at small scales. Nevertheless, the difficulties of *in situ* collection of such data over large areas are such that analysis of Landsat data may provide a valuable contribution in many areas where information is limited or altogether lacking. A substantial improvement in orbital data should occur after the launch in the early 1980's of the Landsat follow-on "Thematic Mapper" instrument. Further investigations should address themselves to the improved spectral and spatial resolution, dynamic range and geometric precision anticipated for this mission.

2) The effects of local physical and biotic factors on the spectral reflectance characteristics of common wetland plants require more extensive quantitative research. Several studies have indicated that such factors as climate and tidal regime can extensively influence the "characteristic" spectral signatures of wetland canopies (Anderson *et al.*, 1973; Bartlett, 1979; Carter, 1976). In addition, seasonal changes are important in determining the information content of spectral data for wetlands. A rigorous approach to measurement of these factors in a variety of environments would shed more light on the potential and limitations of quantitative spectral analysis for wetland assessment.

3) The technology for making appropriate atmospheric measurements during satellite overpasses and incorporating them into multi-spectral analysis must be made more reliable and accessible to the potential user community. Recent advances in interpretation

theory and technology, requiring more accurate preprocessing of data not only in analysis of wetlands but in many other natural and agricultural environments, argue for a comprehensive program to provide atmospheric data and correction algorithms on a continuing basis.

It seems likely that, in the forseeable future, wetlands habitat and productivity assessment will rely on a combination of conventional and remote sensing techniques to provide required management information. The statutory requirements for planimetric accuracy will almost certainly continue to require low or medium altitude aerial photography for state and local inventories (Carter, 1978, Penney and Gordon, 1975). Certain types of data will continue to be best accumulated using field sampling procedures whose reliability and methodologies are well known. However, the role of remote sensing can be expanded to efficiently provide some information traditionally gathered by other techniques if the research and operational objectives described above are actively pursued. Achieving an effective match between the potential of remote sensing technology and the existing requirements for habitat information will depend upon quantitative clarification of those factors which combine to produce the spectral signal measured over wetlands. Use of orbital scanners has the potential for synoptic, economical data gathering which would greatly enhance research and management functions in the extensive wetlands of the U.S. East and Gulf Coasts. The optimal mix of conventional techniques with *in situ* and remote spectral methods will depend on the type of data and frequency of update required and the size of the wetland examined.

6. CONCLUSIONS

Remote sensing has established utility in delineation of wetland boundaries and aerial extent and low or medium altitude photography is routinely applied to such tasks by federal, regional and state management authorities. Frequently, the distribution of plant species or species associations can be mapped using remotely sensed data collected for boundary delineation or acquired by high altitude or orbital sensors. Spectral contrast between species of interest can be extensively modified by intraspecific variability in canopy structure and by seasonal changes in canopy and leaf characteristics. Optimization of species discrimination in temperate regions is thus possible through choice of data acquired at appropriate times of year if local seasonal effects are known. Knowledge of species composition acquired through remote sensing can be used to make inferences concerning tidal and salinity regimes and habitats available for marine, estuarine and terrestrial fauna.

Potential exists for quantitative, spectral estimation of emergent biomass for selected wetland plants. More research on spectral characteristics of wetlands and improvement in reliability and availability of atmospheric correction methodologies is needed for widespread implementation of remote sensing for biomass assessment.

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